



Prospectives for China's solar thermal power technology development

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ABSTRACT

China's total installed electrical power capacity reached 700 GW by the end of 2007 and is predicted to surpass 900 GW in 2010. The rapid increase in energy demand and increasing global warming have both pushed China to change its current electrical power structure where coal power accounts for nearly 75% of the total electric power generation. China has already become the world's largest solar water heater producer and user. However, there is still much to be done in the solar thermal power field before its commercialization. Solar thermal power technologies including solar power towers, solar parabolic trough concentrators, solar dish/stirling systems, linear Fresnel reflectors, and solar chimneys have been studied in China since the 1980s. A 10 kW dish/stirling project was funded by the Ministry of Science and Technology (MOST) during 2000–2005 with a 1 MW solar power tower and research of trough concentrator metal–glass evacuated tubes supported during 2006–2010. This paper describes a continued solar thermal power development roadmap in China in 5-year intervals between 2006 and 2025.

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1. Introduction

China currently generates nearly three-quarters of its electricity from coal-fired power stations. In June 2007, it was reported that construction of an average of two new plants was finished every week.

China used to be a major coal exporter, but its exports are decreasing and it may become a net importer soon. Although China is still a major crude oil producer, it became an oil importer in the 1990s. In 2006, China imported 145 million tonnes of crude oil, accounting for 47% of its total oil consumption. As a step toward reducing domestic reliance on coal and oil, the National People's Congress passed a law in Feb 2005 pledging to replace 10% of China's energy consumption with renewable energy resources by 2010 and 15% by 2020 [1]. The Chinese Government has undertaken a series of national programs to promote the development and utilization of renewable energy. These include the Comprehensive Rural Energy Planning and Construction Program; the Rural Electrification Program, which focuses on the development of small hydropower plants; the Brightness Program; the Township Electrification Program and the Wind Power Concession Program. By 2006, the coverage of solar water heaters in China reached 100

million square meters, benefiting about 200 million people. It is expected that the coverage will reach 150 million square meters in 2010 [2]. Besides solar water heaters, other solar-powered appliances are also being developed in China, including solar energy heating and cooling devices, solar energy seawater desalination systems, and solar thermal power systems. The huge desert- and Gobi areas in northwest China hold enormous potential for large-scale deployment of solar thermal power systems. Therefore, solar thermal power can play an important role in meeting the nation's energy demand and reducing greenhouse gas emissions. Photovoltaics are another important area but they will not be discussed here.

2. Deployment forecast for China's solar thermal power market

China has promulgated the Renewable Energy Law and given priority to renewable energy electricity, so electricity generated from renewable energy will soon be connected to the grids, with preferential pricing policies. The extra costs will be covered by public funding [2]. A 1 MW solar thermal power tower named "DAHAN" is being funded from 2006 to 2010 by the Ministry of Science and Technology (MOST). Several companies are developing larger commercial solar thermal power plants in Northwestern China in this five-year period through cooperation with foreign countries. Research on solar thermal power systems with lower

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boiling point working fluids and on related components including trough concentrator absorber tubes is also supported by MOST.

The electrical power consumption in China has been rising fast with China's rapid economic development. China's installed total capacity of electrical power reached 700 GW by the end of 2007 and is predicted to reach 900 GW in 2010 [3]. China is predicted to have the world's largest installed electrical power capacity of 1186 GW by 2020. However, China also has extremely rich solar energy resources and two-thirds of its territory has sunshine for over 2200 h each year. The distribution of China's solar energy resources is illustrated in Fig. 1.

Tibet, Qinghai, Xinjiang, the southern parts of Inner Mongolia, and northern Shanxi, Hebei, western Jilin, and the middle-, and southwest parts of Yunnan all receive relatively large amounts of solar radiation. In particular, areas on the Qinghai-Tibetan Plateau receive the most. However, many of those areas are far from population centers and a suitable transmission infrastructure will be very expensive. Thus, trade-offs are needed to find proper sites for large-scale solar thermal power systems.

A number of international projects to develop commercial trough- or tower solar power plants typically with capacities of 10–100 MW are being pursued by industry in various countries with many companies actively participating in the research, development, and marketing of tower- and trough solar power systems. The author's team is in charge of the 1 MW 'DAHAN' system's design and construction. Research on other solar thermal power systems and components is also in process. Current conditions obtaining for solar resources, energy shortages, environmental protection, and technology developments in China suggest an installed capacity of 100 GW solar thermal power in China is

possible by 2025. This would account for about 10% of China's electrical power installed capacity by then. Reaching this target will involve several phases with the main characteristics of each phase during 2006–2025 listed in Table 1.

3. Industrial plan for concentrated solar power plant cost reductions

Significant cost reductions will be required to secure market acceptance. Cost reductions come from technical improvements, larger plant sizes, and large volume production. Over the next 20 years, the major technical development tasks are to lower the average 2006 system cost by 50% to reach a price 1.3 times the price of coal-fired power (0.030–0.042 \$/kWh) by 2025.

- Power tower systems should be developed in such a way that they can meet the medium to base-load needs in the large-scale power market. In addition, they should compete with conventional fossil-fueled power technologies in price, with leveled energy costs (LEC) reaching 0.04–0.06 \$/kWh.
- Parabolic trough power systems as a distributed medium load mode, should be capable of competing with conventional fossil-fueled power in a large-scale medium load market with a competitive cost of 0.04–0.06 \$/kWh.
- Dish/Stirling systems will also be developed as distributed power systems for specific markets. Because of their restricted sizes, the future for dish technology lies primarily in decentralized power systems and remote-, stand-alone power systems.

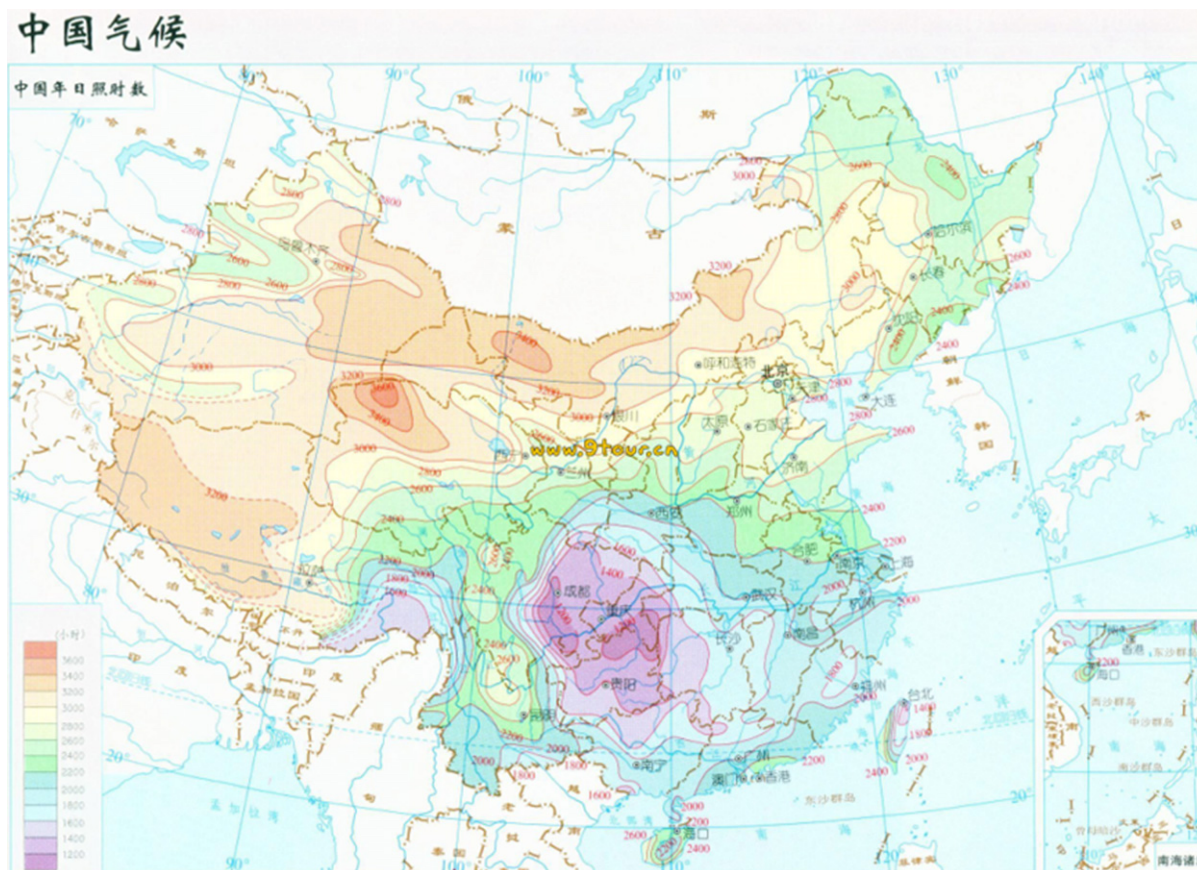


Fig. 1. China's solar energy resources distribution.

Table 1

Main characteristics of each development phase.

Year	Main activities	Target
2006–2010	1. Key equipment development: large-scale heliostats, high-temperature absorbers and high-temperature thermal storage 2. Experimental solar thermal power plant construction 3. Research base establishment 4. Construction of large-scale commercial hybrid power plant integrating solar energy and fossil fuels	Proving technical feasibility
2011–2015	1. Demonstration of 10–100 MW solar thermal power systems 2. Demonstration of large-scale high-temperature, low-cost solar thermal storage technology 3. Experimental demonstration of Brayton-Rankine combined power cycle	Large-scale demonstration
2016–2020	1. Commercial application of 100–1000 MW solar-only power generation technology 2. Large-scale commercial application of high-temperature thermal storage technology	Commercial application
2021–2025	1. Large-scale commercial applications of solar-only centralized and distributed power generation systems	Large-scale commercial application

4. China solar thermal power technology development roadmap

To obtain cost reductions it is necessary to achieve market acceptance, China cannot depend on imported technologies. Therefore, the Chinese government has funded research on various solar thermal power systems to develop domestic systems independently. The following plan prepared by the author covers all the possible directions that need effort. No other countries are developing dependence on solar power systems.

4.1. 2006–2010

4.1.1. Research on components and system integration

4.1.1.1. Power tower systems. The key research needs include research on mirrors and heliostats, receivers, working media, molten salt heat transfer, high-temperature thermal storage materials and heat exchange systems, air absorber developments, solar thermal power system design, system control methods, combined solar and conventional coal-fired power plants, and system test and evaluation methods [4].

4.1.1.2. Parabolic trough systems. The key research needs include research on metal-to-glass sealing techniques that enable evacuated tubes to maintain high-temperature differences between their inner and outer surfaces of up to 500 °C, high-temperature selective solar coatings (450 °C), evacuated tube production techniques, and evacuated tube quality control methods.

4.1.1.3. Dish/stirling system. The key research needs include core components of 10–30 kW stirling engines that are matched with dish concentrators with a stirling engine prototype.

4.1.1.4. Line-focusing Fresnel reflector (LFR) Systems. Research is needed on high-temperature selective coatings that can withstand 450 °C in air, design of large LFRs, and 2000 m² system integration and testing.

4.1.1.5. Novel power systems. Pilot thermo-chemical gas production systems combined with solar concentrators operating at temperatures of 200–300 °C will be developed.

4.1.1.6. Capacity building and resource investigations. A national solar experimental test platform and base will be established. A team is expected to be organized equipped with the ability to integrate research, design, material supply, manufacturing, installation, operation and management. The nationwide solar Direct Normal Insolation resource distribution will be surveyed to facilitate location, selection, and planning for solar thermal power

plants. Research on funding systems and financial policies for solar thermal power will also be strengthened.

4.2. 2011–2015

4.2.1. Technology demonstrations and development of production capacity

4.2.1.1. Power tower systems. Develop 10–100 MW power systems and large power rating receivers and test high-temperature (600–1300 °C) and large capacity thermal storage systems.

Develop 10 MW solar power towers with an air receiver and construct a 10 MW experimental Brayton cycle system.

4.2.1.2. Parabolic trough systems. Apply evacuated tube manufacturing techniques to large-scale production of solar parabolic trough collectors, complete product pilot tests and evaluate tube quality and lifetime, develop quality standards and test platforms, construct large-scale parabolic trough collector fields with performance tests, and construct a large-scale experimental parabolic trough power plant.

4.2.1.3. Dish/stirling system. Develop 10–30 kW Stirling engine prototype that can be matched with a dish concentrator.

4.2.1.4. LFR systems. Develop performance test method for LFR collector field and test large demonstration fields with performance predictions. Design and integrate a 10–100 MW solar LFR power system.

4.2.1.5. Novel power technologies. Medium-temperature solar thermo-chemical gas production will be studied with a Megawatt range experimental power system expected to be developed.

4.2.1.6. High-temperature thermal storage and heat transfer technologies. Develop inorganic nonmetallic sensible heat storage materials and high efficiency heat exchanger structures, pilot test high-temperature heat storage systems utilizing inorganic salt and metal phase change materials, develop thermal energy storage systems using metal–nonmetallic compound materials and high-grade thermal energy transfer techniques combined with chemical reactions.

4.3. 2016–2020

4.3.1. Construction of commercial solar power plants

4.3.1.1. Power tower systems. Construct and operate 10–1000 MW commercial solar power plants.

4.3.1.2. Parabolic trough systems. Construct and operate parabolic solar concentrating fields with capacities of 10–1000 MW.

4.3.1.3. Parabolic dish systems. Commercialize 25–40 KW Stirling engines. Develop dish cluster power generation systems and high-temperature air heating systems using multiple dishes connected in parallel or series.

4.3.1.4. LFR systems. Construct and operate 10–1000 MW LFR power plants.

4.4. 2021–2025

4.4.1. Establish large-scale commercial power plants featuring mature technologies

4.4.1.1. Power tower systems. Commercialize multi-tower power plants with capacities of 1000 MW Brayton- and Rankine-combined cycle solar power plants.

4.4.1.2. Parabolic trough systems. Develop 1000 MW parabolic trough power systems, accelerate experimental studies of vacuum tube lifetimes, commercialize low cost, large-scale, high-temperature energy storage systems, and combine concentrating parabolic troughs and power tower systems.

4.4.1.3. Solar dish systems. Commercialize solar dish systems with connection to the electrical grid.

4.4.1.4. LFR systems. Commercialize 10–1000 MW LFR power plants with electrical grid connections.

5. Conclusions

With its rapid economic development, China is facing significant pressure from energy- and environmental constraints. The

exploration and utilization of renewable energy resources play a significant role in increasing energy supplies, improving the energy mix, and alleviating environmental concerns. China must solve the contradiction between energy supply and demand to achieve sustainable development. The deployment forecast for the China solar thermal power market given in this paper outlines a plan for Concentrated Solar Power plant cost reductions followed by commercialization with details for each 5-year development period.

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